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# THE DISTANCES OF THE STARS.[1]

By Heber D. Curtis.

The subject which I hope to treat in a rather popular fashion to-night is somewhat bewildering to astronomer and layman alike because of the immensity of the quantities involved, and I shall try to make what I have to say sufficiently general in its character to avoid confusing unduly those not directly engaged in astronomical work with too great a mass of enormous figures. So I must, at the outset, beg the indulgence of the astronomers present if I attempt to make some points as clear as I may by the use of examples and illustrations which may seem to them rather elementary. On the other hand, it may be necessary also to refer occasionally to more technical matters, for which I must ask the temporary indulgence of those who, except for their interest in astronomy, do not belong to the class I have just named.

First, to define a term which we shall have frequent occasion to use,—just what do we mean by the parallax of a star? The process of finding the distances of the stars, in its essentials, is exactly that used by a surveyor who desires to find the distance from his camp of some inaccessible mountain. In most such cases it would be absolutely impossible for the surveyor to measure the distance in the ordinary way with tape or chain because of the roughness of the country intervening, or the absolute inaccessibility of the mountain peak. To determine, then, the distance of such an inaccessible object, the surveyor proceeds as follows (Fig. I) :—

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[1] An illustrated popular lecture delivered before the Astronomical Society of the Pacific on July 20, 1911.

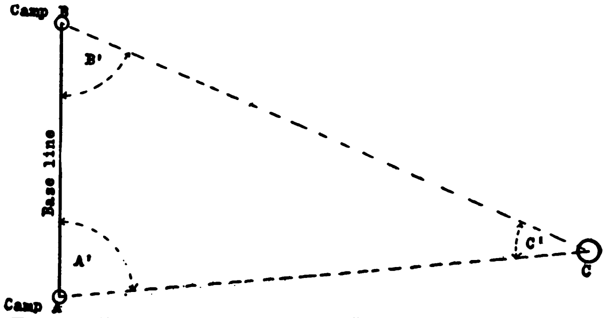

FIG. I.—DIAGRAM ILLUSTRATING DETERMINATION OF THE DISTANCE OF AN INACCESSIBLE OBJECT.

From his camp at A he first measures off with his tape as accurately as possible the distance to a second camp at B, so that from either station A or B he can see the other station and the peak whose distance he desires. Then setting up his theodolite at station A, he measures the angle A′ between station B and the mountain C; when this is done he goes to station B and similarly determines the angle B′ at that point between station A and the mountain. Since he has actually measured the length of his base line between the two stations he now knows one side and two angles of the triangle ABC and can find by a very simple calculation the lengths of the other two sides of this triangle, and the side from A to C is the distance he requires. Since the sum of the angles of a plane triangle is equal to two right angles, he could subtract the sum of angles A′ and B′ from 180° and obtain angle C′. This angle, at the mountain, made by the chosen base line may be regarded as the parallax of the mountain, though, as a matter of fact, the surveyor seldom uses this term, preferring to reckon the distance AC directly in miles. But the astronomer has to do with distance so inconceivably great that a unit of a trillion miles is none too large, and finds it very convenient to speak of the parallax of a star—that is, the size of the angle C′—more frequently than he does of the actual distance.

The surveyor finds a base line of a few hundred yards in length sufficient for determining many distances, but sometimes for objects a long way off he will measure off a base line as long as possible, often several miles in length, for the longer the base line the more accurately he will be able to determine the distance of the remote object. But an enormously greater base line is required for the distances which obtain in astronomy. The nearest of the heavenly bodies to us is the Moon, nearly two hundred and forty thousand miles away, and for the determination of this great distance the astronomer can still find a long enough base line on the Earth. (Fig. II.) In this case let us assume that we have two observatories making observations on the position of the Moon at the same time; the two observatories are quite well separated on the Earth, and because we know the positions of the two observatories A and B we know the length of the base line from A to B. So the astronomer can solve this great triangle with a base line several thousand miles long in much the same way as does the surveyor for a base line a few miles in length. Here again we may consider the angle C′ (which is the angle made at the Moon by the distance between the two observatories) as the parallax of the Moon, though the astronomer, for the sake of uniformity, always reduces this to the angle made by the semidiameter of the Earth as seen from the Moon.

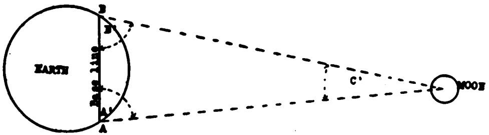

FIG. II.—DIAGRAM ILLUSTRATING DETERMINATION OF THE DISTANCE OF THE MOON.

When we come to the distance of the stars, however, no base line on the Earth is long enough, and we must search for something much greater. The Earth in its orbit makes this base line for us, and enormous as it is it is all too small for the purpose. (Fig. III.) If the position of a star in the sky be determined

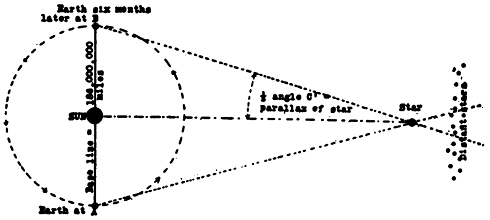
Earth six months later at B
SUN
Base line = 186,000,000 miles
½ angle C′ = parallax of star
Star
Distant stars
Earth at A

FIG. III.—DIAGRAM ILLUSTRATING DETERMINATION OF THE DISTANCE OF A STAR.

as accurately as possible in March, for example, and then again in September after an interval of six months, the Earth will meanwhile have carried us around to the other side of the Sun, one hundred and eighty-six million miles from the position in March. Then if a slight difference is found in the position of the star between the two observations we have determined the angle C′, and as we know the length of the base line from A to B we can determine the distance of the star. The parallax of a star, then, is the angle made at the star by the radius of the Earth's orbit. If there were an astronomer on the star and he could see the Earth (which would be impossible), the parallax of the star would be one half the small angle made by the Earth moving from one side of its orbit to the other. Put in another way, the parallax of a star means how big a line ninety-three million miles long would look when seen from the distance of the star. The slight shift in the position of the chosen star is determined from measures made to fainter and presumably much more distant stars, though this is somewhat of an assumption and not always true, giving rise occasionally to a *negative* result for the parallax, which would indicate that the chosen star is really farther away than the comparison stars used.

To determine this small shift in position is one of the most difficult, if not absolutely the most difficult problem in astronomy, and has taxed the utmost skill of astronomical science for three quarters of a century, with results which we must confess are very meager at best. Why? Because the stars are so infinitely distant that this small angle, the parallax, is for most of them vanishingly small. There is no star known whose parallax reaches one second of arc; a second of arc is less than one-millionth of the distance around the circumference of a circle; on a circle three feet in diameter it is less than one ten-thousandth of an inch, and all the skill of instrument-makers can scarcely guarantee such accuracy in dividing a circle. Move the Golden Gate two hundred thousand miles away, and it would subtend one second of arc; a second of arc is the size a tennis ball would look if seen from a distance of eight miles; an ordinary man two hundred and fifty miles away, if we could see him at all, would be one second of arc high. Yet ninety-three million miles, the radius of the Earth's orbit, looks smaller than this when seen from the very nearest of all the stars. *Alpha Centauri* in the southern heavens is, so far as we know, our nearest neighbor among the stars and has a parallax of three quarters of a second of arc; this translated into miles means that *Alpha Centauri* is nearly twenty-six trillion miles from us —twenty-six million times a million miles. It would be a difficult thing to determine whether a man one mile away were seventy-one or seventy-two inches high, to say nothing of attempting such a feat if he were two hundred and fifty miles away, and no one would be bold enough to say that we know the parallax of *Alpha Centauri* within one per cent of the truth; yet an error of one per cent in this vast distance would mean an uncertainty in the distance of over two hundred billion miles. It is, of course, futile to attempt to conceive of such enormous distances. Few of us have any very clear conception of what a distance of five miles really means; sea captains, surveyors, and trained military men have some conception of larger distances, say of fifty to one hundred miles, but one million has very little meaning to any of us. Half a century ago, when curious wagers were frequently made in England, one English gentleman bet another five hundred pounds that it would be impossible to make one million strokes of the pen in a month; this means about one stroke a second, ten hours a day, for thirty days. The wager was won, but only by having doctors and attendants on hand during the last weeks to massage the almost worn-out wrist. So the distance to the Sun, ninety-three million miles, has no real meaning. Yet *Alpha Centauri* is nearly three hundred thousand times as far away as the Sun. The familiar and somewhat hackneyed illustrations give us no help. We are familiar with the statement that a lightning express, sixty miles an hour, day and night, year in, year out, would need one hundred and seventy-seven years to reach the Sun, but this illustration leaves us no better off than we were before as far as the comprehension of even this relatively small astronomical distance is concerned.

So meaningless are these almost infinite distances that no attempt is ordinarily made by astronomers to express the distance of a star in miles. This is a unit far too small; even if we use the distance from the Earth to the Sun as a unit we would have inconveniently large numbers. The astronomer ordinarily speaks of the distance of a star simply by mentioning its parallax; for instance, he will say that such and such a star has a parallax of seven hundredths of a second. Frequently, however, he expresses its distance by the use of a foot-rule longer than any of the relatively small distances afforded by our own solar system. Light travels at the rate of one hundred and eighty-six thousand miles a second, roughly a distance equal to seven times around the Earth in one second of time. It takes light about eight minutes to reach us from the Sun, and the foot-rule which the astronomer occasionally uses is the enormous distance, nearly six trillion miles, which light would traverse in one year. It would take light over four years to reach us from *Alpha Centauri,* so it is convenient to say that *Alpha Centauri* is four light-years away. Doubtless many of the fainter stars are at the very least one thousand light-years away; that is, if that light were blotted out to-night the world would not know of it for a thousand years.

Later I shall treat of more modern methods which have within the last few years given us a far better idea of the average distances of the stars than we could ever hope to obtain by the older methods, but first will treat very briefly of the processes ordinarily used to determine the parallax of a star, which is nothing more nor less than finding its very slight shift in position as the Earth moves from one side of its orbit to the other. The older methods used were those depending upon astronomical instruments which serve to measure the position of the stars with great accuracy—the meridian circle, the micrometer, and the heliometer. It would only confuse were I to attempt to describe the various sources of error which must be allowed for as far as possible. Suffice it to say that so minute are the quantities to be measured that a most searching analysis must be made of all the errors unavoidably inherent in the instruments and the measures made with them. The errors of the carefully cut screws and the delicately divided scales must be investigated, also the personal errors of the observer; the conditions under which the observations are made must be kept the same as far as possible; errors have been found due even to the variation on the position of the stars from the meridian; when all these are allowed for, the difference in the seasons six months apart at which the observations must be made may give rise to minute errors which are practically impossible to eradicate entirely. Of the older visual methods, doubtless the heliometer gave the most accurate results. The heliometer is a telescope whose object-glass is cut in half, and each half can be delicately moved with reference to the other, forming two images of the same star, or two stars whose distance apart is to be measured can be made to coincide and the distance read off. The telescope tube can be rotated in its bearings, or even object-glass and eye-end interchanged, and from the manner of using the instrument many of the instrumental errors of the ordinary micrometer can be thus balanced and made harmless. The heliometer is not a common instrument; there is one in America, that at Yale College Observatory, with which considerable work of value in this field has been done. While these visual methods have done very valuable service, photography to-day is much the most promising of the older methods.

If two photographs are taken of the same region six months apart, the shift of the star under discussion can be determined with a measuring microscope. The same minute precautions must be taken, for the quantities to be measured are only a few hundred thousandths of an inch. If desired, the photographs can be made on the same plate, side by side. This is the basis of KAPTEYN'S method, which promises well for searching out the larger parallaxes from a large number of stars. In this method a plate is taken of a region of the sky containing four or five separate images of all the stars in the region which can be reached with an exposure of moderate length. The undeveloped plate, shielded from light, is then stored away for six months, when a new set of five images close to the former five is secured, and the process repeated again six months later. Then the plate is developed and measured, and the parallax of the stars secured with reference to the parallax of all the stars on the plate. As there are many chances for deterioration of the plate, however, most parallax workers prefer to take the exposures on different plates, instead of on the same plate. In this photographic method the longer the focal length of the telescope employed the larger will be the scale of the plate, and the greater the resulting accuracy of the measures. Accordingly, the most accurate photographic parallaxes are secured to-day with instruments of great focal length. A program of great value has been recently carried through by Dr. SCHLESINGER with the great Yerkes telescope; the results indicate a higher degree of accuracy than has been hitherto attained, and afford us the best values attainable by present methods in determining the distances of individual stars.

What are the results of the efforts which have been made to solve this exceedingly difficult astronomical problem? The distances of only about three hundred and fifty stars have been separately determined, and those distances which can be assumed as fairly accurately known are doubtless less than two hundred—surely a very small proportion of even the naked-eye stars. As to the accuracy of the results, they are perhaps more disappointing to the layman than to the astronomer, who realizes the difficulty of the problem.

Before proceeding farther a point must be explained which will be necessary for some of the conclusions drawn, which, though very elementary from the standpoint of the astronomer, may not be so clear to others. Astronomers have a way of estimating the accuracy of a result by what is called its probable error. To illustrate: Suppose you were given the task of measuring the length of a city block with nothing better than an ordinary foot-rule, and to get as accurate a result as possible you repeated the measure twenty-five times. It would be found that no two of the measures would agree, but that some would be several inches larger or smaller than the general average of all twenty-five measures. This average of the measures would be the most probable value of the length of the block, and from the deviations of all the separate measures from this average value the surveyor would calculate a quantity which he calls the probable error of the result. This probable error is, to a great extent, a measure of the accuracy of the work; manifestly the probable error of one hundred such separate measures would be smaller than the probable error of only five measures, and the probable error of twenty-five carefully made measures smaller than that from twenty-five carelessly made measures. The probable error, then, is a measure of the accuracy of a result as far as mere accidental errors are concerned; but a point must be emphasized here, as it has at times been overlooked, even by men of considerable experience. While the probable error takes account of the *accidental* errors of measurement, and to that extent is a measure of the accuracy of a result, it entirely fails to indicate the inaccuracy of a result in so far as that result is affected by *constant* errors —that is, those errors which come from permanent faults in the instrument or in the methods of making the observations. To return to the former illustration, suppose that the foot-rule used was only one one-hundredth of an inch too long; then from this *constant* error the side of the block would come out six or eight inches too short, even though the probable error calculated from twenty-five measures gave reason to suppose that it was a much more accurate value than this. It is generally estimated that the *actual* error of a result may be, because of *unknown* constant errors, three to five times the size of the calculated probable errors. The actual uncertainty, then, in the determination of the distances of the stars is certainly larger than the computed probable errors.

DISTANCES OF *SIRIUS* AS DETERMINED BY VARIOUS OBSERVERS.

| Distance, Light-Years. | Probable Error, Light-Years. | Instrument. | Observer. |
|---|---|---|---|
| 9.6 | ± 3 | Meridian circle | HENDERSON |
| 17.3 | ± 9 | " " | MACLEAR |
| 7.6 | ± 2 | " " | BELOPOLSKY |
| 9.6 | ± 1 | " " | FLINT |
| 8.8 | ± 0.2 | Heliometer | GILL and ELKIN |
| 8.0 | ± 0.3 | " | GILL and ELKIN |
| 8.8 | ± 0.2 | " | GILL |

The above table gives an example of a fairly well determined distance, as the different values are in quite good agreement, and from the size of the probable errors it will be seen that, though the uncertainty of the results is really to be measured by trillions of miles, still we have a very fair idea of the approximate distance of this star. A less favorable result is shown from a tabulation of some of the different values for the distance of 1830 *Groombridge*:—

DISTANCES OF 1830 GROOMBRIDGE AS DETERMINED BY VARIOUS OBSERVERS.

| Distance, Light-Years. | Probable Error, Light-Years. | Instrument. | Observer. |
|---|---|---|---|
| 14.2 | ± 8 | Meridian circle | PETERS, 1842 |
| 18.1 | ± 2 | Heliometer | SCHLÜTER, 1842 |
| 95.9 | ± 75 | Micrometer | STRUVE, 1848 |

| | | | |
|---|---|---|---|
| 98.8 | ± 75 | Heliometer | JOHNSON, 1852 |
| 142.0 | ±203 | " | JOHNSON'S results as revised by AUWERS |
| 36.6 | ± 10 | Micrometer | BRÜNNOW, 1871 |
| 40.7 | ± 12 | Meridian circle | JOST, 1890 |
| Negative result | | " " | FLINT, 1894 |
| 32.6 | ± 10 | Photography | RUSSELL, 1910 |

The more modern results for 1830 *Groombridge* agree fairly well, but even for these it will be seen that the computed probable error of the result indicates an uncertainty in the distance of over ten light-years; in other words, the calculated uncertainty in the distance of this star is over twice the entire distance to our nearest neighbor, *Alpha Centauri*. This point is emphasized without any desire to depreciate the results secured in this field, but simply to make plain, as far as possible, that except for the nearest stars the problem of determining the distance is almost insoluble by present methods, for it will be at once seen that for the more distant stars the probable error of the result would be greater than the determined parallax. This will be somewhat clearer from the following tabulation:—

AVERAGE PROBABLE ERRORS OF PARALLAX DETERMINATIONS.

(Derived from numerous published results by various observers.)

| Method. | Average Probable Error. |
|---|---|
| Meridian circle, micrometer, etc...... | 0.040 seconds of arc |
| Heliometer ........................ | 0.035 " " " |
| Photographic methods .............. | 0.026 " " " |
| Photographic methods (from 26 of the most modern determinations with long-focus instruments, mainly by SCHLESINGER) ............. | 0.014 " " " |
| The average parallax of all stars to the seventh magnitude is probably not greater than ................ | 0.008 " " " |

It will be seen that the average parallaxes of even the brighter stars are considerably smaller than the calculated probable error of even the most refined modern photographic methods; it is possible to determine the distances of stars out to about one hundred light-years with some degree of confidence, but beyond this point the inaccuracy of our best methods is equal to or greater than the very quantities we are trying to determine. From the direct methods, then, we have learned only the distances of some of our very nearest neighbors, and valuable as the results are in giving us some idea of the size of the stellar universe, they are in no sense representative of the universe of the stars as a whole. The individual distances of stars farther away from us than one hundred light-years must always remain only very imperfectly known, unless more powerful and accurate methods of attacking the problem directly are discovered in the future.

THE TEN NEAREST NEIGHBORS OF THE SUN.

| Star. | Magnitude. | Parallax. | Distance in Light-Years. | Distance in Miles. |
|---|---|---|---|---|
| *Alpha Centauri* | 0.9 | 0″.76 | 4.3 | 25 trillion miles |
| *Lalande* 21185 | 7.5 | 0 .47 | 6.9 | 41 " " |
| 61 *Cygni* | 6.1 | 0 .41 | 8.0 | 47 " " |
| *Sirius* | —1.4 | 0 .38 | 8.6 | 51 " " |
| *Cord. Zones* $5^h$,243 | 8.5 | 0 .32 | 10.2 | 60 " " |
| *Tau Ceti* | 3.7 | 0 .32 | 10.2 | 60 " " |
| *Nu*$^1$ *Draconis* | 4.9 | 0 .32 | 10.2 | 60 " " |
| *Procyon* | 0.7 | 0 .30 | 10.9 | 63 " " |
| *Lacaille* 9352 | 7.1 | 0 .29 | 11.1 | 66 " " |
| *Epsilon Indi* | 4.8 | 0 .28 | 11.6 | 69 " " |

Note that in the above table both bright and faint stars occur, —i. e. we cannot assume that because a star is faint that it is, because of that fact, exceedingly remote; it is not impossible that other quite faint stars may be found to be relatively close.

Pessimistic as the foregoing summation of three-quarters of a century of effort may seem, it is fortunate that we have another method of determining, not the distance of some particular star, but the average distances of large classes of stars, with considerable accuracy, even though this average distance is so great that even the most modern photographic methods are useless. These results are made possible by the results secured for more than a century by astronomers who have devoted their energies to the determination of the exact positions and the proper motions of the stars, in combination with the most modern results secured by the spectrograph. We may say that to secure these results the oldest astronomy has joined hands with its most modern development, and this newest knowledge, in its most accurate form, is less than one year old. One of the most important links in the chain is that formed by the work of the Lick Observatory during the past fifteen years, for Dr. CAMPBELL and his associates have there secured with the spectrograph the largest collection of determinations of the velocities of the stars in existence.

I will first endeavor to put in popular form some of the principles underlying this indirect method of finding the average distances of the stars. In a sense, the problem goes back to the familiar illustration of the surveyor and his measured base line. As you have seen, the enormous base line made by the Earth swinging from one side to the other of its orbit has

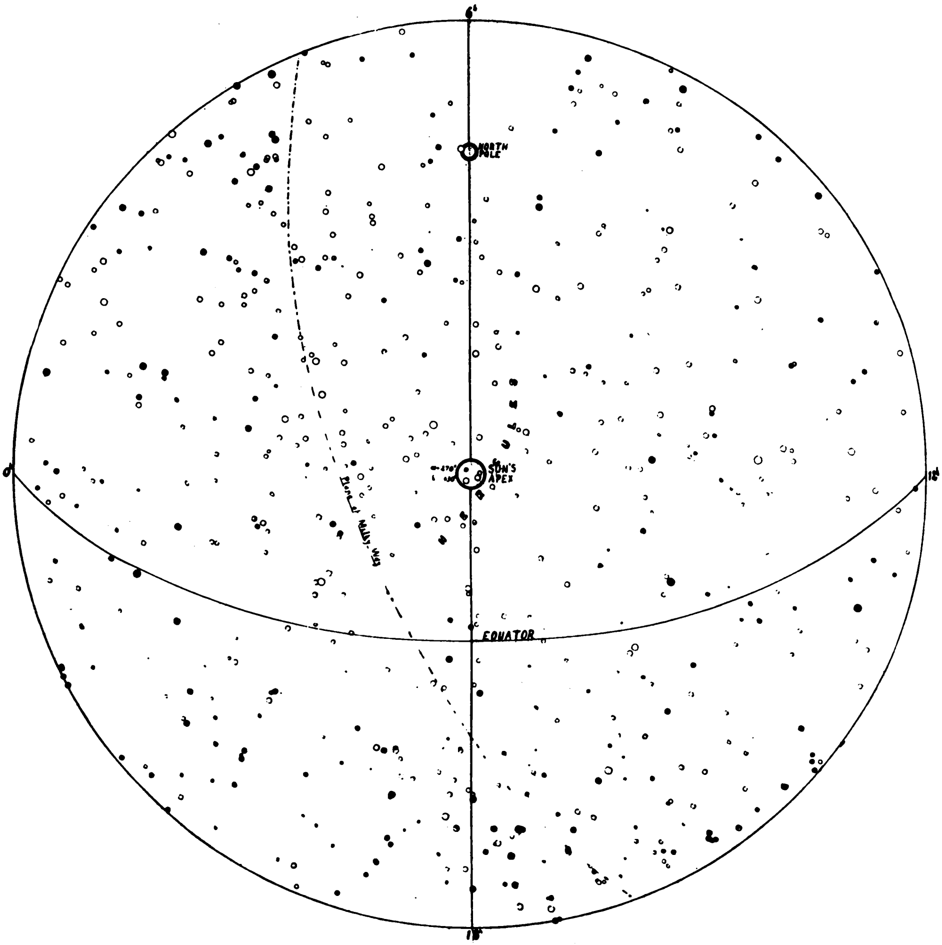

FIG. IV.—VELOCITIES ABOUT SOLAR APEX.

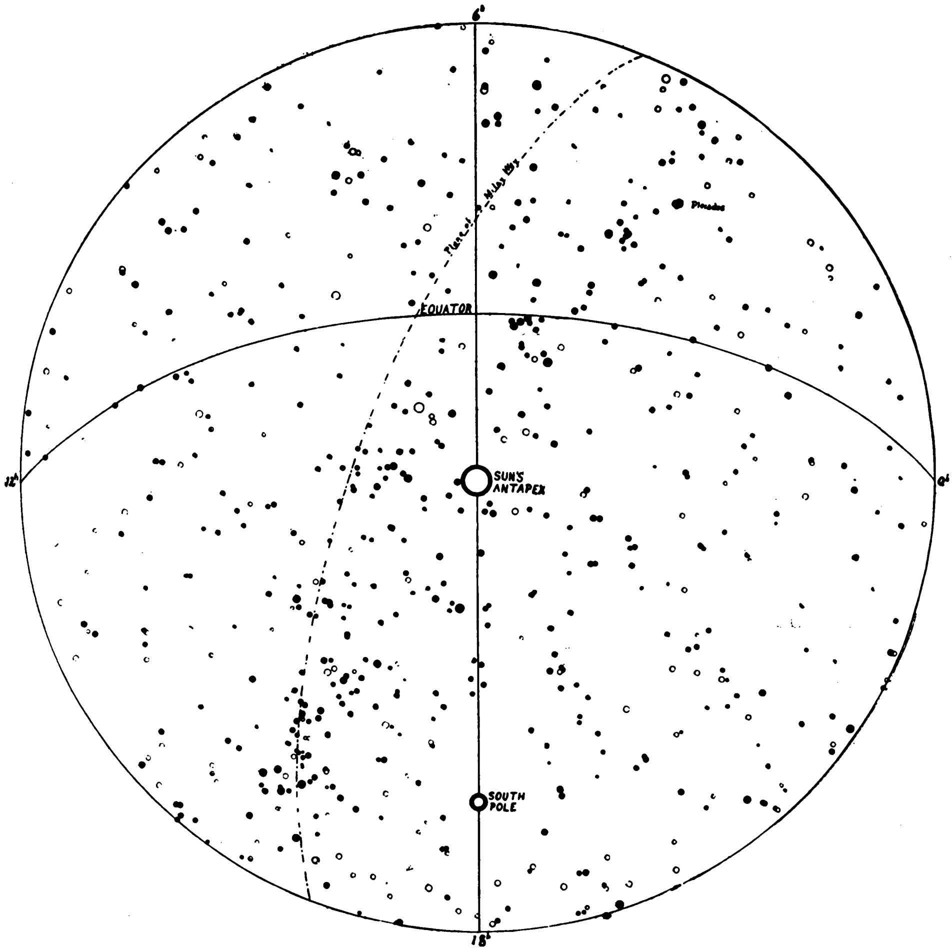

Fig. V.—Velocities About Solar Antapex.

been found to be all too small. But the spectroscopic results show that the Sun, with its attendant retinue of planets, is itself moving through space at the very great velocity of twelve miles in every second of time. From this motion we have, in the course of time, a very much greater base line. A star which would shift its position in the sky only one one-hundredth of a second of arc while the Earth moved from one side to the other of its orbit would show a shift of nearly two seconds after one hundred years from the motion of the

Sun through space, and two seconds of arc is a quantity much easier to determine than one one-hundredth. Similarly, the small proper motions of the stars, imperceptible in a year's time, become noticeable in a century. The element of time now becomes an all-important factor, for several generations of astronomers have given us the minute changes in position from which we derive the motions of the stars across our line of vision, the so-called proper motions of the stars. By methods into which it is not necessary to enter here, the spectroscope enables us to tell how fast a star is moving in a direction directly toward or directly away from us, known as the velocity in the line of sight, or the radial velocity of a star. Now it is found that in one part of the sky the stars seem to be coming toward us at an average rate of twelve miles a second, while in the opposite half of the sky they are on the average moving away from us at this rate. The inference is clear that it is our Sun which is moving toward the one part of the sky and away from the other at this rate of speed. This can be seen graphically in Figures IV and V. Figure IV represents the brighter stars in that half of the sky surrounding the apex, the point toward which the Sun is moving; open circles represent stars whose radial velocities are such that they appear to be coming toward us, the full black circles stars which are moving away from us, apparently. It will be seen at once from Figure IV that nearly all the stars around the apex seem to be coming toward us, while around the edge of the map the open and dark circles are about equally divided. In Figure V, which shows the half of the sky around the antapex as a center, it is just as clear that the Sun is receding from that part of the sky, for here nearly all the stars are moving away from us. The older astronomy, instead of using the then unknown velocities in the line of sight, made use of the observed proper motions of the stars to determine the point toward which the Sun is moving. But the spectroscope has one overwhelming advantage; knowing the distances of so few of the stars, a study of the proper motions will give a pretty good value of the direction the Sun is going, but a very imperfect idea of the rate of its motion, while the velocities determined by the spectroscope are absolutely independent of the distance of the star, so that it not only gives the direction in which the Sun is moving through space, but gives also the rate of speed, something which the study of proper motions could do only roughly and with many assumptions as to the distances of the stars involved. The point toward which the Sun is moving is in the constellation of *Hercules,* about fifteen degrees southwest of the bright star *Vega.*

Perhaps an elementary illustration at this point will aid in making clearer the means by which the results of proper motion studies and velocities in the line of sight are combined so as to give the average distances of the stars. Imagine ourselves on a very large level plain, and all around at a great distance a large number of objects too far away to be observed except through telescopes, and moving at random in all directions over the plain. With our telescopes we could study and tabulate the motions for these moving objects so that we could say, for instance, that these objects were moving, on the average, one degree of arc per hour across the field of view of our telescope. This deduction from the "proper motions" of these bodies would in itself tell us nothing as to the distances of the objects. But now suppose that in some way we could learn that these objects were men, and that they were moving at an actual rate of one mile per hour, on the average, across our field of view, some moving much faster than this, some much more slowly. Then the problem would be comparatively simple, for it would resolve itself into the question; How far away must an object be so that a base line of one mile would look like one degree? The answer would come out that these men must be, on the average, fifty-seven miles from us. Some might be much closer, and some much farther away, but if their average movement across the field of our telescope were one degree per hour, and we could find that their average actual movement in this time and in this direction was one mile, we should know that their average distance was as given above. Now with the stars, several generations of astronomers, patiently accumulating accurate positions with their meridian circles, have ascertained the average motions across the sky of several thousand stars, with a high degree of accuracy. Fifteen years' work, mainly at the Lick Observatory, has now made available through the spectrograph, for over a thousand stars, the fact that the stars have a certain average velocity in miles per second. For instance, Dr. CAMPBELL found for one hundred and eighty stars resembling our Sun in type that their average cross proper motion in the sky from the values derived by Professor Boss was about 0.11 seconds of arc per year, while their average speed toward us, given by line of sight velocities determined with the spectrograph, was 8.9 miles per second, or two hundred and eighty million miles in a year. How far away must a base line of that length be so as to look only 0.11 seconds of arc in size? The answer comes out, in miles, five followed by fourteen ciphers, or over ninety light-years. The problem is much more complicated than in the simple illustration of the distant moving objects on a plain, for the value of the Sun's own motion through space must be eliminated from the observed radial velocities of the stars, and that part only of the proper motion used which is not affected by the motion of the Sun through space.

Classified with regard to the elements shown by their spectra, it is found that the stars fall into a relatively small number of well-marked spectral types which are designated by letters; it would only confuse here to go into the distinctions between the various types, and it will be sufficient to say that the stellar types lettered O and B are supposed to be young stars, in the earliest stages of their development; those lettered A are still farther along; those lettered F and G are more nearly like our own Sun in spectrum and presumably at about the same point in their evolution; while those lettered K and M are on the way to stellar old age and extinction. Now, perhaps, the most remarkable result from the radial velocities is that the average velocities of these different types of stars, when the effect of the solar motion is removed, varies with the type.

STELLAR RADIAL VELOCITIES AS FUNCTIONS OF SPECTRAL TYPES.

| Type. | No. | Average Radial Velocity. |
|---|---|---|
| O and B | 141 | 5.5 miles per second |
| A | 133 | 6.1 " " " |
| F | 159 | 8.6 " " " |
| G and K | 529 | 9.4 " " " |
| M | 72 | 10.3 " " " |
| Nebulæ (KEELER) | 13 | 14.5 " " " |

It will be seen that there is a steady increase in average velocity according to the type of the star's spectrum, and these results open many very interesting questions. Can it be, as Dr. CAMPBELL puts it, that all matter is not equally old from a gravitational standpoint? These results show, moreover, that to find the average distances of the stars we cannot consider all stars as a whole, but must find their average distances by classes. The next table shows Dr. CAMPBELL'S results for the distances of the different types of stars from a comparison of their average cross-motions with their average radial velocities.

AVERAGE DISTANCES OF STARS BY SPECTRAL TYPES.

| Type. | No. | Average Yearly Cross-Motion. | Average Radial Velocity per Second, Miles. | Average Relative Parallax. | Average Distance, Light-Years. |
|---|---|---|---|---|---|
| B-B5 | 312 | 0″.0078 | 3.9 | 0″.0061 | 534 |
| B8-B9 | 90 | .0182 | 4.2 | .0129 | 253 |
| A | 172 | .0368 | 6.5 | .0166 | 196 |
| F | 180 | .1075 | 8.9 | .0354 | 92 |
| G | 118 | .0748 | 9.9 | .0223 | 146 |
| K | 346 | .0516 | 10.4 | .0146 | 223 |
| M | 71 | .0384 | 10.6 | .0106 | 308 |
| | 1289 | | | | |

It will be seen at a glance that the younger B type stars are on the average very far away from our system; these are nearly all situated in or near the Milky Way. On the other hand, the F and G type stars, most like our own Sun, are nearest of all to us. It seems as though our Sun were one of a great cluster of similar stars fairly near to us as astronomical distances go.

Professor Boss, using the proper motions alone, with the aid of the velocity of the Sun in space, secured results very similar to these, though in his results the difference between the various types was less marked, due doubtless to the fact that in his solution he was able to use over four thousand stars, going down nearly a magnitude fainter than the stars used by Dr. CAMPBELL. These two epoch-marking pieces of work, attacking the problem from different standpoints and in a marked degree supplementing each other, appeared almost simultaneously a few months ago, and give us a far more accurate idea of the size of the universe than has hitherto existed. The general results may be shown graphically in Figure VI. Here it will be seen that the average distance of the stars most like our Sun in type is roughly one hundred light-years, and this circle represents also about the limit of the older methods. Outside of this will come the K and M type stars, and farthest out of all the younger B type stars at the enormous average distance of five hundred light-years. These results apply only to the brighter stars; how much farther out the fainter stars may extend we can only guess. The small circle in the center of the diagram is twenty-four light-years across and would contain the ten nearest neighbors of the Sun. Some idea of the scale of the figure may be gathered from the fact that the dots over the letter *i* are two thousand times the distance from one side of *Neptune's* orbit to the other,—in other words, nearly three million solar systems could be placed in the area of the dot.

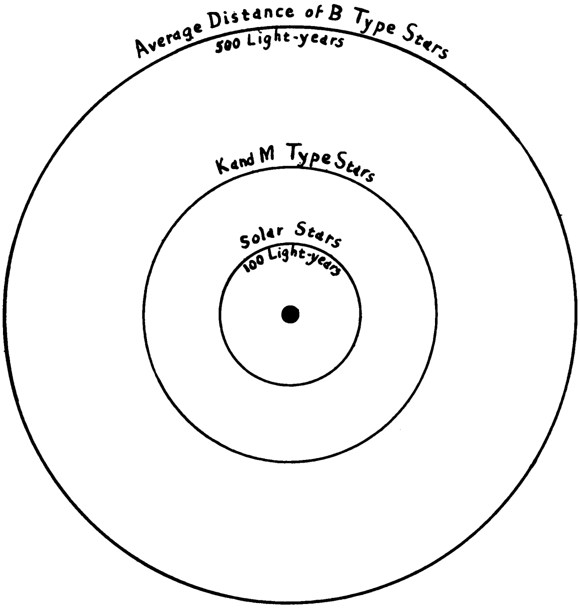

FIG. VI.—AVERAGE DISTANCES OF THE BRIGHTER STARS.

The small circle in the center is twenty-four light-years across and would contain the ten nearest neighbors of the Sun. The dots over the letter *i*, on the scale of the diagram, are two thousand times the diameter of the solar system.

If the Sun were removed to a distance of thirty light-years, it would be just visible to the naked eye as a sixth-magnitude star, and at the average distance of the B type stars would be visible only in a telescope; in other words, as stars go, it is a rather small and inconspicuous object.

Only less important than the more accurate data so recently obtained as to the size of the stellar universe are the remarkable facts that the stars of different ages are moving at different average velocities through space. To quote from Dr. CAMPBELL's recent paper:[1] "Why should not the materials composing a nebula or class B star have been acted upon (by gravitation) as long and as effectively as the materials in a class M star? KEELER's observations, it is true, would indicate that the planetary nebulæ are traveling at least as rapidly as a well-developed star, but the Great Nebula in *Orion* is radially at rest with reference to the stellar system, and the latter condition may exist in the other extended nebulosities. The established fact of increasing stellar velocities with increasing age suggests the questions: Are stellar materials in the ante-stellar state subject to Newton's law of gravitation? Do these materials exist in forms so finely divided that repulsion under radiation pressure more or less closely balances gravitational attraction? Does gravitation become effective only after the processes of combination are well under way? Are the high observed velocities of the planetary nebulæ due in some or all cases to the gravitational disturbances which accompany a conversion of ordinary stars into planetary nebulæ; such disturbances in velocity and in physical condition as might transpire through the close approach of two massive bodies? . . . The proper motion data do not indicate the presence of a single class B star in a great sphere, concentric with the Sun, which must contain hundreds of stars of other spectral classes, A to K, inclusive. We are led to believe that the present class B stars assumed stellar form in regions relatively near to their present positions. . . . The absence of class B stars in our vicinity may indicate primeval vacancy in this region, or the development of stars in this region to an effective age beyond that corresponding to the class B spectrum. . . . It seems not unreasonable to suppose that the large average distances of the class M or red stars are the result of high velocities for long periods of time; and that their nearly uniform distribution over the stellar sphere is due in a large part to the disturbing action of other individual stars through whose spheres of influence they have passed, and in part also to their low radiating efficiency, which renders invisible any red star which may exist in distant regions of the Milky Way."

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[1] *Lick Observatory Bulletin,* No. 196.

A reasonable conclusion, in the light of our most recent knowledge, would be that such an object as the wonderful cluster in *Hercules* is probably at least one thousand light-years away. There are many similar clusters in the sky; nearly all lie in or near to the Milky Way, and this is the part of the sky where we find practically all the class B stars, with average distances for the brighter stars of about five hundred light-years. It may be much farther than this from our system, though we have no definite knowledge on this point. Such a cluster would then be at least one light-year across in its densest portion, and the stars which seem so closely packed are really separated by enormous distances. The stars so close together in a photograph of this cluster that they appear to touch must be at the very least thirty billion miles apart, or six times the diameter of the solar system; this, then, may be looked upon as almost a small universe in itself, perhaps containing twenty-five thousand separate suns and with possibilities for unnumbered planets circling about them. Similar dimensions probably obtain for such a great spiral nebula as *Messier* 51, in which we see exemplified the process of evolution of stellar systems from the originally formless diffused nebulosities. The larger nebulæ seem to have drawn into themselves most of the material lying around them, so that they are in regions which are to some extent drained of stars. A casual inspection of photographs of the nebula in *Orion* will show this, and it has been corroborated by actual count and tabulation of the star density around such nebulæ.

In the clusters and particularly in the spiral nebulæ we see the proofs of the evolutionary process through which matter has gone and is going to form the stars. Is there some greater scheme underlying the whole mighty fabric? Is this inconceivable space filled with millions of mighty suns, clusters, and nebulæ arranged on any system? To a certain limited extent we may give an affirmative answer. Perhaps the best proof of this lies in the distribution of the nebulæ. The positions of the clusters and nebulæ in the sky have been plotted by Mr. S. Waters, and it is found that nearly every cluster lies in or near to the Milky Way, while practically all the nebulæ group themselves as far as possible from the Milky Way. This arrangement cannot be chance, but just what it means we can only guess as yet.

The human mind finds itself placed between two infinities—that of the infinitely small and the infinitely great. From the bulb of one of these incandescent lights the maker has exhausted nearly all the air, yet there remain in it after this process a number of molecules millions of times greater than the total number of stars visible in the mightiest telescope, particles smaller than the resolving power of any microscope, but moving rapidly in their minute paths, a microcosm of the infinitely small, as difficult to conceive of as the cosmos of the infinitely great. Great as is our own Sun, we find it difficult to imagine that it is only a very ordinary and inconspicuous unit among hundreds of millions of similar units. That these millions of massive bodies should be traveling through space in all directions at speeds of five to ten miles in every second of time is likewise difficult to conceive, but more wonderful and difficult of conception than all is the vast realm of space in which they move under the influence of that still unsolved mystery, gravitation,—a space so vast that the distances apart of the separate units are to be measured by trillions and quadrillions of miles, a realm so nearly infinite in extent that it is practically so, as far as our finite-thinking minds can grasp it. Truly a supremely vast and supremely wonderful universe. And what may be still farther out, beyond that part to which our mightiest telescopes can reach? We do not know.